Diffusion imaging of post-mortem human brains: DW-SSFP at 7T provides improved crossing fibre estimates

Sean Foxley[1], Saad Jbabdi[1], Wilfred Lam[1], and Karla Miller[1]
[1]*FMRIB Centre, University of Oxford, Oxford, Oxfordshire, United Kingdom*

INTRODUCTION: Post-mortem human brain imaging is of interest both to validate in-vivo measures and to scan for long periods of time to achieve high spatial resolution.[1] Use of diffusion weighted steady-state free precession (DW-SSFP)[2] has been demonstrated to perform significantly better than diffusion-weighted spin echo techniques[3] for post-mortem human brain tractography at 3T. However, even with 18-24-hour scans, limitations in SNR have made it difficult to estimate voxel-by-voxel secondary fibre populations[3]. This indicates worse contrast-to-noise ratio than in current in-vivo protocols, an affect that varies across brains due to lack of control over time-to-fixation. In this work we explore DW-SSFP at 7T with two different b_{eff} values to investigate potential improvements in secondary fibre estimations.

METHODS: Data were acquired in post-mortem human brain at 3T (n=3, Siemens Trio, 12 channel head coil) and 7T (n=2, Siemens, 32 channel head coil for whole brains, 28 channel knee coil for half brains). DW-SSFP was implemented with a 3DFT readout acquiring a single line per TR. All gradients were balanced except a single diffusion gradient between excitation and readout. Data were acquired with 1mm isotropic resolution. One challenge of DW-SSFP is that there is not a single, well-defined b-value (instead, the q-value is well defined). As with previous work, we report effective b-values for tissue with a given T1, T2 and diffusion coefficient. In addition to scans with strong diffusion weighting, eight scans were acquired with a slight diffusion gradient (q=10-20 cm^{-1}). These images fulfil the role of b=0 scans in standard diffusion imaging while avoiding banding artefact associated with balanced SSFP acquisitions. Diffusion data were acquired over 50 directions for a total of 18 hours. 3T data were acquired with TE/TR=26/35ms, flip angle=35˚, delta=19ms, G=3.8G/cm (assuming T1/T2=400/45ms, D=8e-4mm^2/s, this gave a b_{eff} =4000s/mm^2). 7T data were acquired with TE/TR=21/30 and 25/34ms, flip angle=30˚, delta=13 and 17ms, and G=5.6 G/cm (b_{eff} of 4000 and 7000 s/mm^2 assuming T1/T2=500/40ms). All data were processed using FSL and Matlab. Individual acquisitions were registered to correct for B0 drift and eddy-current distortions before averaging. First and second fibre orientation populations were estimated using a modified version of BEDPOST to model SSFP signal, including T1 and T2 maps. Brain masks were produced using BET and white matter masks were generated from maps of mean diffusivity.

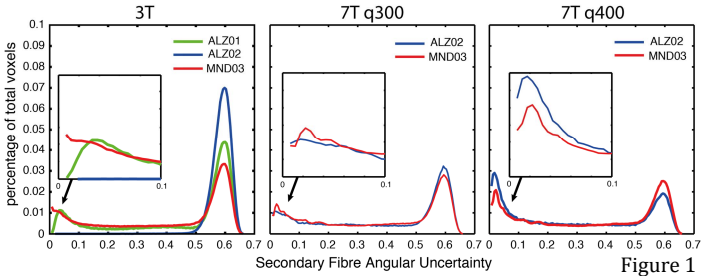
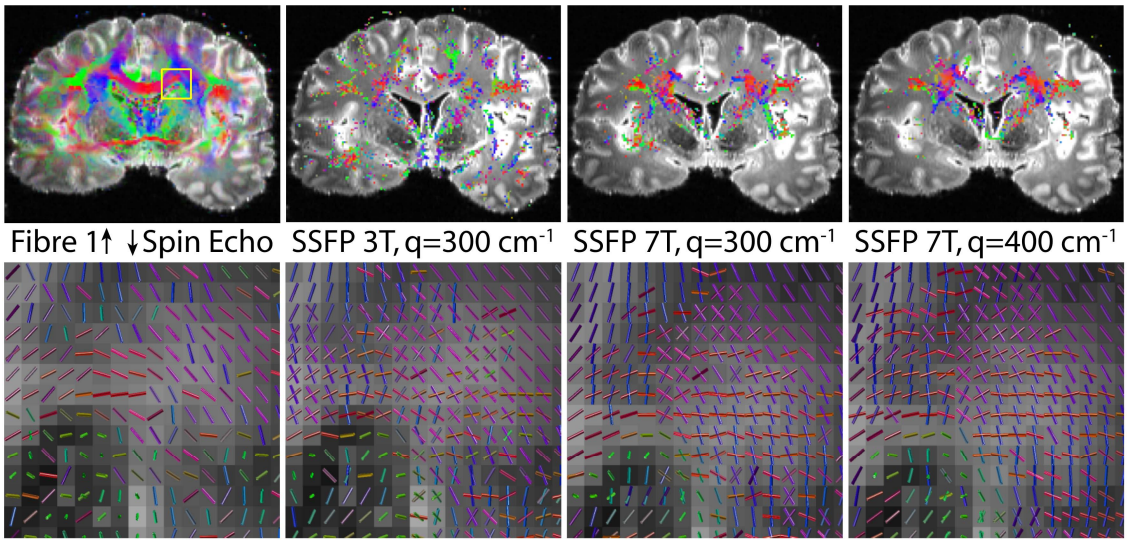


Figure 1

RESULTS: SNR of b_{eff}=0 data was computed and pooled for all 3T and 7T data. The SNR at 7T (67±18) was statistically significantly larger (p=0.006, Student's t-test) than that at 3T (15±6). Figure 1 shows normalized histograms of angular uncertainty across protocols for secondary fibre estimation, which is reflective of the contrast-to-noise ratio. The relative probability of improved secondary fibre estimation increases with both field strength as well as b_{eff}, as seen by the respective increasing peak at low uncertainty (inset plots in figure 1). Figure 2 demonstrates crossing fibres estimates from all three DW-SSFP protocols, as well as our previous spin-echo protocol[4]. The color maps on the top row show regions where the second fibre is supported by the data according to automated relevance determination. The bottom row shows both fibres in the centrum semiovale where the corticospinal tract crosses callosal projections (yellow square in spin echo image). This brain had been scanned with spin-echo, and demonstrates incremental improvements with DW-SSFP, 7T and b-value.

DISCUSSION: These results improve on previous post-mortem diffusion imaging based on several advances: DW-SSFP over spin echo; 7T over 3T; improved receive coils; and stronger gradients. While DW-SSFP clearly represents one advance, this was insufficient at 3T to provide second-fibre estimates in one brain (ALZ02). Imaging at 7T did generally improve second fibre estimates, but was not without its difficulties. We observed decreased estimation of secondary fibre estimations in lateral regions near the cortex at 7T compared with 3T (fig 2, top row) in a spatial pattern that suggests RF inhomogeneity. Efforts to account for this will be investigated in the future. Nevertheless, significant improvements in accuracy of estimations were demonstrated in deeper white matter tracts, supporting the continued development of acquiring diffusion weighted data at 7T using DW-SSFP.



References:

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[2] Buxton, MRM 1993
[3] Miller, NeuroImage 2012
[4] Miller, NeuroImage 2011